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AGC METHOD AND CIRCUIT FOR DIGITAL RADIO RECEIVER

BACKGROUND OF THE INVENTION

The present invention relates to a digital radio receiver, or in particular to an AGC (automatic gain control) method and an AGC circuit for controlling

5   the level of the received signal.

The level of the signal received by the receiver used for digital radio communication changes with the propagation characteristics. An AGC circuit is required, therefore, for controlling the input

10 signal of a demodulator at a constant level regardless of a change in the input signal level. Generally, an AGC circuit uses an amplifier, and the level of the received signal is regulated by changing the gain of the amplifier for amplifying the input signal. A

15 method is widely known, in which a RSSI (received signal strength indicator) signal obtained by logarith- mic amplification and envelope detection of the input received signal is used to control the gain of the amplifier.

20   An AGC method using an interval average of the RSSI signal will be explained with reference to Fig. 1.

Fig. 1 is a block diagram showing an example configuration of a conventional AGC circuit for

25 performing the control operation using the interval

average of the RSSI signal. In Fig. 1, reference
numeral 101 designates an input terminal, numeral 102
an amplifier (for example, a variable gain amplifier),
numeral 103 a RSSI circuit, numeral 104 an A/D (analog-

5 to-digital) converter, numeral 105 an interval average
calculation circuit, numeral 110 a gain control unit,
numeral 111 a D/A (digital-to-analog) converter and
numeral 112 a demodulation circuit.

In Fig. 1, the signal received by the digital

10 radio receiver is applied through the input terminal
101 to the amplifier 102 and the RSSI circuit 103. The
RSSI circuit 103 logarithmically amplifies the received
signal applied thereto from the input terminal 101, and
after envelope detection, outputs a RSSI signal. The

15 RSSI output signal, as the result of logarithmic
amplification and envelope detection, is proportional
to the logarithm of the received signal level.

Fig. 2 is a block diagram showing in detail
an example of the RSSI circuit 103. In Fig. 1, the

20 received signal from the input terminal 101 is applied
to an envelope detector 103a, and the output signal of
the envelope detector 103a is applied to a logarithmic
amplifier 103b, where it is logarithmically amplified.
The signal thus logarithmically amplified is further

25 applied to a low-pass filter (LPF) 103c for removing
the amplitude variations caused by modulation, and
outputted as a RSSI signal. The low-pass filter is
intended to remove the amplitude variations due to the

modulation and desirably has a time constant of not

less than 2 symbols but not more than about 10 symbols.

In the description of embodiments that follows, the

time constant of the low-pass filter is assumed to be 2

5 symbols, for example.

Fig. 3 is a characteristic diagram showing

the voltage of the RSSI output signal of the RSSI

circuit versus the power of the received signal. The

received signal power on the abscissa is shown by

10 logarithmic scale, and therefore the output voltage of

the RSSI signal is proportional to the logarithm of the

received signal power.

The RSSI output signal of the RSSI circuit

103 is converted into a digital signal in the A/D

15 converter 104, and applied to the interval average

calculation circuit 105. The RSSI signal, that has

passed through the low-pass filter 103c having a time

constant of 2 symbols, for example, is sampled by the

A/D converter 104 for every 2 symbols. The RSSI signal

20 sampled and converted into a digital signal in this way

is hereinafter called an instantaneous value r of the

RSSI signal. In the following explanation, the signal

processing from the A/D converter 104 to the D/A

converter 111 is performed by the digital signal

25 processing, and the period of the operation clock

signal (period of the operation clock timing) of this

digital signal processing is two symbols. In the radio

communication system, signal is generally transmitted

and received on a frame unit basis of a predetermined data length. For example, when one frame is 40 msec and formed by 192 symbols, 2 symbols has a period of about 0.42msec.

5   The interval average calculation circuit 105 calculates the input RSSI signal (the instantaneous value r of the RSSI signal) with a time constant (time tX) of a period longer than several tens of symbols, and applies the interval average value rX of the

10   instantaneous values r of the RSSI signal providing the result of calculations to the gain control unit 110.

In the gain control unit 110, a control signal g for controlling the gain of the amplifier 102 is produced based on the input interval average value

15   rX, and after being converted into an analog signal by the D/A converter 111, applied to the amplifier 102.

In the amplifier 102, the received signal input from the input terminal 101 is amplified with a gain corresponding to the control signal g input

20   through the D/A converter 111, and the amplified signal is applied to the demodulation circuit 112.

The signal output from the amplifier 102 is a modulated wave, and this modulated wave signal is subjected to frequency change, detection and signal

25   point determination in the demodulation circuit 112 thereby to retrieve the information contained in the modulated wave.

The signal received by the digital radio

receiver is segmented for each frame, and the frame is roughly configured of a control information section containing the sync data and a data section. For example, Fig. 4 is a diagram for explaining the frame structure of a sync burst frame according to ARIB STD-T61 providing a standard specification of FDMA (frequency division multiple access). Fig. 5 is a diagram for explaining the frame structure of a traffic channel according to the same specification.

Figs. 4 and 5, reference characters "LP+R" designates a linearizer preamble and ramp-up section, "Pb" a preamble section, "RI" a communication information channel section, "SW" a sync word pattern section, "PI" a parameter information channel section, "G" a guard time section, "Tch a traffic channel section, and "UD" an undefined section. The numeral values described under the respective symbols represent the number of bits for the areas thereof, respectively. The sections "LP+R" and "Pb" make up a control information section, and the remainders constitute a data section. The AGC operation is performed using a part of "LP+R" or "Pb".

In the specification of Fig. 4, the modulation scheme is the $\pi/4$ shift QPSK (quaternary phase shift keying), a modulation rate of 4.8 kbaud, a frame length of 40 msec, and 192 symbols (384 bits; 1 symbol = 2 bits) per frame.

Fig. 6 is a diagram showing an example of a

transmission pattern. In Fig. 6, "SB_0" and "SB_1" are frames of the sync burst shown in Fig. 4, and "TchN" (N: natural number) a frame of the traffic channel shown in Fig. 5. In the example of Fig. 6, after two

5   frames of sync burst are transmitted, N+1 frames of the traffic channel are transmitted. An explanation will be given below of the case in which the signal of the transmission pattern shown in Fig. 6 is received by the receiver.

10   Figs. 7A to 7E are time charts showing the signal waveforms of the various parts for explaining the operation of the AGC circuit of Fig. 1. Specifically, these time charts represent the signal waveforms of the respective parts produced by the AGC operation

15   performed with the interval average value rX of the RSSI signal using the AGC circuit shown in the block diagram of Fig. 1 in the case where the signals of frames n to n+k (n, k: integer) are applied to the receiver. Fig. 7A shows a received signal, Fig. 7B an

20   instantaneous value r of the RSSI signal, Fig. 7C an interval average value rX of the RSSI signal, Fig. 7D a control signal g, and Fig. 7E an input signal to the demodulation circuit 112. In Figs. 7A and 7E, the actual signal is a modulate wave and only the envelope

25   is plotted by solid line while the modulated wave signal is not shown.

        The AGC operation using the interval average value rX of the RSSI signal will be explained with

reference to Figs. 7A to 7E.

As shown in Fig. 7A, the received signal of frames n to n+k is input within the time of frames n-1 to n+k+1. In the frames n-1 and n+k+1 where the received signal is not input, therefore, the instantaneous value r of the RSSI signal assumes a minimum level, while the instantaneous value r of the RSSI signal assumes the level R shown in Fig. 7B in the frames n to n+k where the received signal is input.

The most simple frame structure is configured of preamble and data. The frame n is configured of a preamble and data as shown in Fig. 8A, and the frames n+1 to n+k may each be configured of data only as shown in Fig. 8B. A specific example of the preamble and the data is Nf = 192 symbols and Np = 44 symbols.

As shown in Fig. 7C, the interval average calculation circuit 105 determines the interval average value of the instantaneous values r (i.e. the average value of the instantaneous values r of the SSI signal during the time length tX) of the RSSI signal with a long time constant of not less than several tens of symbols, and therefore the interval average value rX takes a time for rise. The interval average is defined as an average value of the instantaneous values during a predetermined time length tX before the ith instantaneous value ri (i: arbitrary natural number) detected, and is determined at each detection time point (for every two symbols in the case under

consideration) of the instantaneous value r.

Thus, as shown in Fig. 7D, the control signal g is gradually attenuated after assuming a maximum gain at the head of the frame n. As a result, as shown in

5 Fig. 7E, the signal applied to the demodulation circuit 112 becomes an excessive input in the head portion of the frame n.

SUMMARY OF THE INVENTION

For the reason described above, the AGC

10 operation is required to be performed quickly at the rise time of the received signal level.

Specifically, in the case where the received signal is continuously applied, as shown in the portion following to the heads portion in the frame n and the

15 frames n+1 to n+k in Figs. 7C, 7D, 7E, the AGC operation is required to be performed slowly based on the interval average value rX of the RSSI signal in order to prevent the suppression of the amplitude component contained in the modulated wave. At the rise time of

20 the received signal level, however, a slow pull-in of the AGC operation would make it impossible to follow a sharp rise of the level, and therefore the AGC operation is required to be pulled in quickly.

The RSSI signal is proportional to the

25 logarithm of the received signal level, and therefore by performing the AGC operation using an instantaneous value or a short interval average value (a time

constant not more than several symbols, for example) of
the RSSI signal, a sharp level change of the received
signal can be followed. In the case where a modulation
scheme such as PSK (phase shift keying) or QAM

5 (quadrature amplitude modulation) having no constant
amplitude, however, the amplitude component of the
modulation is contained in the RSSI signal. An AGC
operation performed using the instantaneous value or
the short interval average value of the RSSI signal,

10 therefore, would suppress the amplitude component due
to the modulation. In order to prevent this suppres-
sion, the AGC operation is required to be performed
using a long interval average (a time constant of not
less than the periods of several tens of symbols).

15   In the communication between a fixed station
and a base station, the AGC operation is required since
the propagation characteristics changes when a vehicle
etc. moves within the propagation path therebetween.

      Further, like the radio communications for

20 business or disaster control, in the communication
between a mobile station and a base station, the
propagation characteristics and the received signal
level change not only while the mobile station is
moving, but also after movement of the mobile station.

25 Thus, the AGC operation is required each time of
arrival of the received signal. Also, the received
signal may be as short as only one frame. In the radio
communication for disaster prevention, even the signal

of one frame is important and required to be received positively. Thus, the AGC operation is required which can detect the first frame of the received signal without fail.

5   The object of the present invention is to obviate the disadvantages of the prior art that a sharp level rise of the received signal cannot be followed and to provide an AGC method and an AGC circuit capable of optimum AGC operation both when continuously receiv-

10   ing the received signal and at the rise time of the received signal.

        In order to achieve the object described above, the AGC method according to this invention uses an AGC circuit of the receiver for the digital radio

15   communication and is intended to detect the envelope of the received signal (RSSI signal, for example) and upon detection of a rise of the received signal, perform the AGC operation rapidly.

        Specifically, according to a first aspect of

20   the invention, there is provided an AGC (automatic gain control) method for a digital radio receiver, wherein the gain of an amplifier is automatically changed in accordance with the level of the signal received by the digital radio receiver thereby to control the gain, the

25   method comprising the steps of:

        (a) detecting an instantaneous value of the envelope of the input received signal sequentially at predetermined time intervals;

(b) determining the first interval average value providing an average value of the instantaneous values for a predetermined time length before the instantaneous value detected;

5   (c) determining a difference value between the instantaneous value and the first interval average value;

(d) in the case where the difference value exceeds a predetermined threshold value, setting, upon 10 the lapse of a third predetermined time length from the time when the difference value exceeds the predetermined threshold value, the gain of the amplifier at a value corresponding to the instantaneous value as of the lapse of the third predetermined time length; and

15   (e) maintaining, during a fourth predetermined time length following the lapse of the third predetermined time length, the gain corresponding to the instantaneous value as of the lapse of the first predetermine time, and after the lapse of the fourth 20 predetermined time length, setting, at each time point of detecting the instantaneous value, the gain to a value corresponding to a first interval average providing an average of the instantaneous values during a predetermined time length before the instantaneous 25 value.

According to another aspect of the invention, there is provided an AGC (automatic gain control) method for a digital radio receiver, wherein the gain

of an amplifier is automatically changed in accordance
with the level of the signal received by the digital
radio receiver thereby to control the gain, the method
comprising the steps of:

5   (a) detecting the instantaneous value of the
envelope of the input received signal sequentially at
predetermined time intervals;

         (b) determining the first interval average
value providing an average value of the instantaneous

10   values for a first predetermined time length before the
instantaneous value detected, and determining the
second interval average providing an average of the
instantaneous values during a second predetermined time
length shorter than the first predetermined time length

15   before the instantaneous value detected;

         (c) determining the difference value between
the instantaneous value and the first interval average
value;

         (d) in the case where the difference exceeds

20   a predetermined threshold value, setting the gain of an
amplifier at a value corresponding to the second
interval average value during the second predetermined
time length before the instantaneous value as of the
lapse of the third predetermined time length from the

25   time when the difference exceeds the predetermined
threshold value; and

         (e) maintaining, during a fourth predeter-
mined time length following the lapse of the third

predetermined time length, the gain set in step (d),

and upon the lapse of the fourth predetermined time

length, setting, for each detection time point of the

instantaneous value, the gain to a value corresponding

5 to the first interval average value during the first

predetermined time length before the instantaneous

value.

In the AGC method according to this inven-

tion, the time before the lapse of the predetermined

10 time after the difference value exceeds the predeter-

mined threshold value following the input of the

received signal is sufficiently long to converge the

second internal (short interval) average value.

Further, the time before the lapse of the

15 third predetermined time length and the fourth

predetermined time length after the difference value

exceeds the predetermined threshold value following the

input of the received signal is sufficiently long to

converge the first interval (long interval) average

20 value.

Furthermore, in the AGC method according to

this invention, the RSSI signal is detected, and the

instantaneous value of the detected RSSI signal is

assumed to be the instantaneous value r of the envelope

25 of the received signal.

According to still another aspect of the

invention, there is provided an AGC (automatic gain

control) circuit comprising an amplifier supplied with

the signal received by a digital radio receiver, the
amplifier controlling the gain by changing the gain
automatically in accordance with the signal level of
the input received signal, the circuit further

5   comprising:

a detection unit for detecting and outputting
the instantaneous value of the envelope of the input
received signal sequentially at predetermined time
intervals;

10   a first interval average value calculation
unit connected to the detection unit for determining
the first interval average value providing the average
value of the instantaneous values during a first
predetermined time length before the instantaneous

15   value detected by the detection unit;

a second interval average value calculation
unit connected to the detection unit for determining
the second interval average value providing the
average of the instantaneous values during a second

20   predetermined time length shorter than the first
predetermined time length before the instantaneous
value detected by the detection unit;

a difference calculation unit connected to
the detection unit and the first interval average value

25   calculation unit for determining the difference between
the detected instantaneous value and the first interval
average value;

a switching unit for selectively outputting

one of the first interval average value determined by

the first interval average value calculation unit and

the second interval average value determined by the

second interval average value calculation unit;

5   a switching control unit for controlling the

switching unit; and

          a gain control unit connected to the output

of the switching unit for outputting a signal for

changing the gain of the amplifier in accordance with

10 the output of the switching unit;

          wherein in the case where the difference

value calculated by the difference calculation unit

exceeds a predetermined threshold value, the switching

control unit controls the switching unit in such a

15 manner that the second interval average value during

the second predetermined time length before the instan-

taneous value upon the lapse of the third predetermined

time length is applied from the second interval average

value calculation unit to the gain control unit upon

20 the lapse of the third predetermined time length after

the difference exceeds the predetermined threshold

value;

          wherein the switching unit is controlled in

such a manner that the second interval average value

25 during the second predetermined time length before the

instantaneous value upon the lapse of the third

predetermined time length continues to be applied to

the gain control unit during the time before the lapse

of the fourth predetermined time length following the

lapse of the third predetermined time length; and

      wherein upon the lapse of the fourth

predetermined time length, the switching unit is

5 controlled in such a manner that the first interval

average value determined by the first interval average

value calculation unit during the predetermined time

length before the instantaneous value is output to the

gain control unit at each time point of detecting the

10 instantaneous value.

      According to the invention having this

configuration, the AGC operation is pulled in rapidly

at the rise time of the received signal level by

detecting the received signal level. Also, as long as

15 the received signal is received continuously, the AGC

operation is performed at low speed with the long

interval average of the RSSI signal in order to prevent

the suppression of the amplitude component contained in

the modulated wave.

20 BRIEF DESCRIPTION OF THE DRAWINGS

      Fig. 1 is a block diagram showing an example

of a configuration of a conventional AGC circuit.

      Fig. 2 is a block diagram showing an example

of a configuration of a RSSI circuit shown in Fig. 1.

25   Fig. 3 is a characteristic diagram showing

the voltage of the output RSSI signal versus the power

of the received signal in the RSSI circuit shown in

Fig. 2.

Fig. 4 is a diagram for explaining the frame structure of an example of a sync burst frame.

Fig. 5 is a diagram for explaining the frame structure of an example of a traffic channel.

Fig. 6 is a diagram showing an example of a frame transmission pattern.

Figs. 7A to 7E are time charts showing the signal waveforms of various parts for explaining the operation of the AGC circuit shown in Fig. 1.

Figs. 8A and 8B are diagrams showing an example of a frame structure of signal.

Fig. 9 is a block diagram showing an example of a configuration of the AGC circuit according to an embodiment of the invention.

Fig. 10 is a block diagram showing an example of a configuration of the long interval average calculation circuit.

Figs. 11A to 11G are time charts showing the signal waveforms of the various parts for explaining the AGC circuit shown in Fig. 9.

Figs. 12A to 12J are time charts showing the signal waveforms of the various parts for explaining the AGC circuit shown in Fig. 9.

Fig. 13 is a block diagram showing a configuration of an AGC circuit according to another embodiment of the invention.

Fig. 14 is a flowchart showing the operation

of processing a microcomputer according to the embodi-
ment shown in Fig. 13.

DESCRIPTION OF THE EMBODIMENTS

An AGC circuit according to an embodiment of

5   the invention will be explained below with reference to
the accompanying drawings.

Fig. 9 is a block diagram showing an example
of a configuration of the AGC circuit for implementing
the AGC method according to this invention. In Fig. 9,

10   the component elements having the same functions as
those described in Fig. 1 are designated by the same
reference numerals, respectively. Reference numeral
115 designates a long interval average calculation
circuit, numeral 116 a short interval average calcula-

15   tion circuit, numeral 117 an adder, numeral 119 a
switch (SW) for selectively applying the output of the
long interval average calculation circuit 115 or the
output of the short interval average calculation
circuit 116 to a gain control unit 110, and numeral 118

20   a switching control unit for operating the switch 119
in accordance with the output of the adder 117. Now,
the control operation of the AGC circuit according to
this embodiment will be explained with reference to
Fig. 9 and other figures. The signal in the present

25   invention may have either a frame structure as shown in
Figs. 4 to 6, for example, or a simple frame structure
as shown in Figs. 8A, 8B.

In Fig. 9, the signal received by the receiver is applied through an input terminal 101 to an amplifier 102 and a RSSI circuit 103. The functions of the demodulation circuit 112 supplied with the output

5   of the amplifier 102 for performing the demodulation, and the functions of the RSSI circuit 103, the A/D converter 104, the gain control unit 110 and the D/A converter 111 are identical to those of the prior art and therefore will not be explained.

10   The instantaneous value of the RSSI signal r converted into a digital signal in the A/D converter 104 is applied to the long interval average calculation circuit 115, the short interval average calculation circuit 116 and the input terminal on the positive

15   (plus) side of the adder 117.

In the long interval average calculation circuit 115, like in the interval average calculation circuit 105 shown in Fig. 1, the instantaneous value r is calculated with a time constant longer than several

20   tens of symbols at each time point when the RSSI signal (the instantaneous value r of the RSSI signal) input from the A/D converter 104 is detected, thereby determining and outputting the long interval average value r_L of the instantaneous values r of the RSSI

25   signal (i.e. the average value of the instantaneous values r of the RSSI signal during the time length t_L). More specifically, the long interval average calculation circuit 115 calculates, each time the ith

instantaneous value ri (i: arbitrary natural number) is input, a long interval average value r_{Li} which is the average value of the instantaneous values r during the predetermined time length t_L before the instantaneous

5   value ri.

The long interval average value r_L of the instantaneous values of the RSSI signal r output from the long interval average calculation circuit 115 is applied to the terminal a of the switch 119 on the one

10 hand and to the negative (minus) input terminal of the adder 117 at the same time.

On the other hand, the short interval average calculation circuit 116 calculates the short interval average value r_s of the RSSI signal r based on the

15 instantaneous value r of the RSSI signal input from the A/D converter 104 is calculated with a time constant as short as several symbols at each time point when the instantaneous value r is detected. Thus, the short interval average value r_s of the instantaneous values r

20 of the RSSI signal (i.e. the average value of the instantaneous values r of the RSSI signal during the time length t_s) is determined and applied to the terminal b of the switch 119. More specifically, the short interval average calculation circuit 116

25 calculates, each time the ith instantaneous value ri is applied thereto, a short interval average value r_{si} which is the average value of the instantaneous values r during the predetermined time length t_s before the

instantaneous value ri.

Fig. 10 is a block diagram showing an example
of a configuration of the long interval average
calculation circuit 115 including multipliers 120, 122,
5   an adder 121 and a delay element 123. In Fig. 10,
reference character r(m) designates a RSSI signal
output from the A/D converter 104, which, as described
above, is a signal sampled for each two symbols, for
example. Character $r_L(m)$ designates a long interval
10   average value r_L calculated, and character m designates
a sample number p thereof which is assumed to be a
constant of 0.03. Fig. 10 can be expressed as an
equation below, in which the output $r_L(m)$ is the sum of
r(m) multiplied by p plus the smoothed output $r_L(m-1)$
15   two symbols before, multiplied by (1-p). The delay
element 123 is for delaying one sample, i.e. two
symbols.

$$r_L(m) = p \times r(m) + (1-p)r_L(m-1)$$

In the case where the sampling period of the
20   RSSI signal is two symbols and p is 0.03, the long
interval average value converges to about 80 % for 120
symbols (60 samples).

The short interval average calculation
circuit 116 has a similar configuration to the long
25   interval average calculation circuit 115 shown in Fig.
10, where p is given as 0.3. The output rs(m) of the
short interval average calculation circuit is applied
to the terminal b of the switch 119, which output rs(m)

converges to about 75 % for eight symbols (4 samples).

The switch 119 connects the terminal d selectively to one of the terminals a, b, c in response to a signal from the switching control unit 118. When the
5 terminal d is connected to terminal a, the long interval average value r_L input from the long interval average calculation circuit 115 is applied to the gain control unit 110. When the terminal d is connected to the terminal b, on the other hand, the short interval
10 average value r_s input from the short interval average calculation circuit 116 is applied to the gain control unit 110. When the terminal d is connected to terminal c, the gain control unit 110 holds the output immediately before the particular connection. The terminal c
15 of the switch 119 is supplied with no signal.

Specifically, the gain control unit 110 includes a sample hold unit, for example, for holding the immediately preceding input signal (the short interval average value r_s, for example) while no signal
20 is input thereto.

In the adder (difference calculation unit) 117, the difference value Δri ($\Delta ri = ri - r_{Li}$) between the ith instantaneous value ri of the RSSI signal input from the A/D converter 104 and the long interval
25 average value r_{Li} (i.e. the average value of the instantaneous values during a predetermined time length t_L before the instantaneous value ri) of the RSSI signal input from the long interval average calculation

circuit 115 is calculated, and the difference value Δri thus calculated is applied to the switching control unit 118.

The switching control unit 118 compares the difference value Δri with a preset threshold value Δr_{th}, and by performing the following determining operations (1), (2) and (3), changes the connection of the switch 119 in accordance with the determining operations. In this case, the AGC circuit performs the control operation with clock timings shown in Fig. 12J. In the case where the AGC circuit is in standby state awaiting the arrival of a received signal input, however, the switch 119 normally connects the terminal a to the terminal d.

Determining operation (1): Before a time point where the difference value Δri exceeds the threshold value Δr_{th}, the terminal a of the switch 11 is connected to the terminal d, and the long interval average value r_{Li} output from the long interval average calculation circuit 115 is applied to the gain control unit 110 (low-speed process).

Upon lapse of a predetermined time t_1 from the time point when the difference value Δri has exceeded the threshold value Δr_{th}, the terminal b of the switch 119 is connected to the terminal d, the short interval average value r_{si} output from the short interval average circuit 116 is applied to the gain control unit 110, and the state of the gain control unit 110 is preset by

the value r_{si} (start of high-speed process).

Determining operation (2): At the next operation clock timing after presetting the state of the gain control unit 110 by the short interval average value r_{si}, the terminal c of the switch 119 is connected to the terminal d, and the state of the gain control unit 110 is held (high-speed process).

Determining operation (3): Upon lapse of the predetermined time $t_1 + t_2$ from the time point when the difference value Δri has exceeded the threshold value Δr_{th}, the terminal a of the switch 119 is connected to the terminal d, and the long interval average value r_L output from the long interval average calculation circuit 115 is applied to the gain control unit 110 (low-speed process). In this case, the predetermined time $t_1 + t_2$ is a time period during which the long interval average calculation circuit 115 starts calculation, then converges the calculation and the long interval average value r_L converges.

The long interval average calculation circuit 115 and the short interval average calculation circuit 16 always calculate and output the long interval average value r_L and the short interval average value r_s, respectively, by operating in response to each instantaneous value r of the RSSI signal input at each operation clock timing. When the long interval average value r_L or the short interval average value r_s is applied to the gain control unit 110 from the switch

119, the gain control unit 110 calculates and outputs the control signal g based on the value r_L or r_s applied thereto. In the case where the terminals c and d of the switch 119 are connected to each other, on the

5   other hand, the immediately preceding calculated value of the control signal g is held and output. The control signal g output from the gain control unit 110 is converted into an analog signal by the D/A converter 111, and applied to the control terminal of the

10   amplifier 102 thereby to control the gain of the amplifier 102 by a well-known method.

The amplifier 102 changes the gain in accordance with the value of the control signal input thereto from the D/A converter 111, amplifies the received

15   signal input from the input terminal 101 and applies the amplified signal to the demodulation circuit 112.

Figs. 11A to 11G, like Figs. 7A to 7E, are time charts showing signal waveforms of various parts for explaining the operation of the AGC circuit in the

20   case where the AGC operation is performed by the AGC circuit shown in Fig. 9 for the signal of frame n to frame n+k (n, k: integer) received by the receiver. Figs. 12A to 12J are time charts plotted in enlarged form for the time length of the several tens of symbols

25   from the head of the frame n. The AGC circuit shown in Fig. 9 is operated in synchronous with the operation clock signal shown in Fig. 12J. The operation of the AGC circuit shown in Fig. 9 will be explained with

reference to Figs. 11A to 11G and Figs. 12A to 12I. In

Figs. 11A to 11G and Figs. 12A to 12I, Figs. 11A, 12A

show a received signal, Figs. 11B, 12B an instantaneous

value r of the RSSI signal, Figs. 11C, 12C a long

5   interval average value r_L of the RSSI signal, Figs. 11D,

12D a short interval average value r_s of the RSSI

signal, Figs. 11E, 12E a difference value Δr ($\Delta r = r - $

r_L), Figs. 11F, 12F a control signal g, Figs. 11G, 12G

an input signal of the demodulation circuit 112, Fig.

10   12H the manner in which the switch 119 is controlled by

the switching control unit 18, and Fig. 12I an input

signal of the gain control unit 110. In Figs. 11A,

12A, 11G, 12G, the actual signal is a modulated wave,

and only the envelope is plotted in solid line while

15   the modulated wave signal is not shown.

In Figs. 11A to 11G and Figs. 12A to 12I, the

signal is received from the frame n to frame n+k. As

shown in Figs. 11B, 12B, the instantaneous value r of

the RSSI signal assumes a level R for the frame n to

20   frame n+k, while the instantaneous value r assumes a

minimum level R0 for the other frames. In Figs. 12A to

12I, the signal is assumed to be received even for the

frame n+k+2.

The long interval average value r_L of the RSSI

25   signal is calculated by the long interval average

calculation circuit 115 with a time constant of several

tens of symbols, as shown in Figs. 11C, 12C, and there-

fore the time corresponding to several tens of symbols

is consumed for rise.

The difference value Δr (= $r - r_L$) between the instantaneous value r of the RSSI signal and the long interval average value r_L, as shown in Fig. 11E, is
5 the difference between two signals of different rise time. Therefore, a positive value is exhibited at the rise time and a negative value at the fall time of the received signal level.

The AGC circuit shown in Fig. 9 detects the
10 rise of the received signal level and selects an optimum AGC control method utilizing the character-istics of the difference value Δr described above. Specifically, when the received signal is received continuously, the AGC operation is performed with the
15 long interval average value r_L of the RSSI signal, while at the rise time of the received signal, the AGC opera-tion is performed with the short interval average value r_s of the RSSI signal or the instantaneous value of the RSSI signal.

20   The AGC operation will be described in detail with reference to Figs. 12A to 12I. The power supply (not shown) for the AGC circuit is turn on and the RSSI signal begins to be received. The AGC operation is performed with the long interval average value r_L until
25 immediately after the time point 400 (interval 401) when the signal is received in the frame n. As described above, the long interval average value r_{Li} at the time point when the ith instantaneous value ri (i:

arbitrary natural number) is input is an average value
of the instantaneous values r during a predetermined
time length t_L before the instantaneous value ri.
Therefore, the long interval average value r_L before the
5 time point 400 when the frame n is received is R0, and
gradually increases after the time point 400 (see Fig.
12C). Thus, the difference value Δr (= r - r_L) remains
0 until the time point 400 when the frame n is
received, and subsequently gradually increases (see
10 Fig. 12E).

After the power for the AGC circuit is turned
on, until the difference value Δr exceeds the preset
threshold value Δr_{th} (time point 402) and further a
specified time t_1 elapses at time point 403, the
15 terminal d remains connected to the terminal a of the
switch 119, and the AGC operation is performed by the
long interval average value r_L of the RSSI signal.
Thus, the input signal of the gain control unit 110, as
shown in Fig. 12I, gradually increases from time point
20 400 to time point 403 in accordance with the long
interval average value r_L. Therefore, the signal input
to the demodulation circuit 112 changes in the manner
shown in Fig. 12G.

At the time point 403 upon the lapse of a
25 specified time t_1 from the time point 402 when the
difference value Δr has exceeded the preset threshold
value Δr_{th}, the terminal d of the switch 119 is turned
to the terminal b, and the value of the control signal

g is preset to a value based on the short interval
average value r_s. The value of the control signal g,
after being thus preset, is fixed (the terminal d of
the switch 119 is connected to the terminal c) during

5   the specified time t_2 (until the time point 404 when the
AGC operation is restarted by the long interval average
value of the RSSI signal in Fig. 12G), and at time
point 404, the AGC operation by the long interval
average value r_L is restored (the terminal d of the

10   switch 119 is connected to the terminal a).

The time until the lapse of the predetermined
time t_1 from the time point when the difference value
Δr has exceeded a predetermined threshold value Δr_{th}
after the received signal is input is a sufficient

15   length of time for the short interval average value r_s
to converge.

Further, the time length until the lapse of
the predetermined time t_1 and the predetermined time t_2
from the time point when the difference value Δr has

20   exceeded the predetermined threshold value Δr_{th} after
the received signal input is sufficiently long for the
long interval average value r_L to converge.

In this manner, the predetermined time t_1 is a
time sufficient for the short interval average value r_s

25   to converge, and the predetermined time t_2 is a time
sufficient for the long interval average value r_L to
converge.

In this way, at the time point 403 when the

difference value Δr has exceeded the predetermined

value and the short interval average value rs has

settled during the interval containing no information

after arrival of the received signal of the frame n,

5 the AGC operation is performed by presetting the

control signal g based on the short interval average

value rs, after which the AGC operation is switched to

the one based on the long interval average r_L at the

time point 404 after the long interval average value r_L

10 is settled.

As a result, at the rise time of the received

signal level, the AGC operation is performed quickly

during the interval containing no information in the

frame. As long as the received signal is continuously

15 received, on the other hand, the AGC operation is

performed at low speed with the long interval average

of the RSSI signal in order to prevent the suppression

of the amplitude component contained in the modulated

wave. In this way, the proper AGC method can be

20 selected in accordance with the receiving condition.

Now, with reference to Figs. 12A to 12J, an

explanation will be given of the case in which after

receiving the signal in the frame n+k, no signal is

received in the next frame n+k+1, and the signal is

25 received in the second next frame n+k+2. In this case,

during the time from the time point 405 when the frame

n ends to the time point 408 associated with the frame

n+k+2 (i.e. the time point when the difference value Δr

exceeds the threshold value Δr_{th} (time point 407) and

further upon the lapse of the specified time t_1), the

terminal d of the switch 119 remains connected to the

terminal a. At time point 408, the terminal d of the

5   switch 119 is turned to the terminal b, and the value

of the control signal g is preset to a value based on

the short interval average value r_s.

The required information can be received

efficiently by performing this high-speed process

10   before the end of the interval of the data uniquely

specified for a communication system containing no

transmission information in the received frame (the

interval containing no information in the received

frames (say, LP+R, Pb of Figs. 4 and 5)) after the end

15   of the AGC operation (after the convergence of the

amplitude of the input signal (Fig. 12G) of the

demodulation circuit 112). Specifically, the AGC

operation and the high-speed sync process are performed

during the interval containing no information in the

20   frame n in Figs. 12A to 12I. This requires that the

time constant for determining the short interval

average value r_s for high-speed sync process (the time

length t_s to determine the average value) is set to a

time shorter than the time length of the interval

25   containing no information in the received frame, less

the time required for the AGC operation (the time

length from the time point when the control signal g is

preset to the time point when the amplitude of the

input signal of the demodulation circuit 112 (Fig. 12G)
converges), and also less the time required for the
high-speed sync process. This example will be further
explained with reference to Fig. 4.

5   When receiving the frame of the sync burst
shown in Fig. 4, the linearizer preamble line-up (LR+R)
and the preamble (Pb) are received at the head of the
frame.

        According to the specification shown in Fig.
10   4, the linearizer preamble line-up (LR+R) may or may
not be output from the transmitter, and therefore it is
not determined whether it is contained in the received
signal or not. Also, the preamble (Pb) contains 44
symbols of the fixed pattern. The information to be
15   transmitted is not contained in (LR+R) and (Pb), and
therefore only the preamble (Pb) may be received.
Thus, consider the case in which the preamble (Pb)
alone is received as an interval containing no informa-
tion in the received frame.

20   The period of about 6 symbols is consumed
until the amplitude of the input signal of the
demodulation circuit 112 converges after the control
signal g is preset (time point 403 in Fig. 12F), and
about 15 symbols is additionally required for the high-
25   speed sync process. In the frame of the sync burst
shown in Fig. 4, the preamble (Pb) period is 44 symbols
(88 bits). Thus, the time constant of the short
interval average value is required to be smaller than

the 23 symbols (44 - 6 - 15). In other words, the time

sufficient for the short interval average value to

converge is required to be smaller than the 23 symbols.

As already described, the RSSI signal

5   contains the amplitude component due to the modulation,

and the RSSI signal level changes depending on the

information transmitted. In the case where the AGC

operation is performed in accordance with the long

interval average value r_L of the RSSI signal, the time

10   constant of the long interval average value r_L (the time

length t_L for which the average value is determined) is

required to be at least several tens of symbols in

order to prevent the suppression due to the modulation.

Thus, the time length from immediately after

15   the start of signal reception to the time point when

the difference value Δr of Fig. 12E reaches the

threshold value Δr_{th} (time point 402 in Fig. 12E), plus

the additional lapse of time t_1, is set to a sufficient

time length t_s (t_s is smaller than the time from

20   immediately after start of signal reception to time

point 402, plus t_1) for the convergence of the short

interval average value r_s. Also, the time length from

immediately after start of signal reception to the time

point 403 and additional lapse of the time t_2, on the

25   other hand, is set to a time length t_L (t_L is shorter

than the time from immediately after start of signal

reception to the time point 402, plus t_1 and t_2) suffi-

cient for the convergence of the long interval average

value r_L. The time before the difference value Δr in
Fig. 12E reaches the threshold value Δr_{th} is about one
symbol or two. In the case where the time constant of
the short interval average is set to six symbols and

5 the time constant of the long interval average is set
to 30 symbols, for example, the time t_1 is set to 5
symbols and the time t_2 to 24 symbols.

As described above, according to this embodi-
ment, the difference value Δr (= $r - r_L$) between the

10 instantaneous value of the RSSI signal and the long
interval average value r_L is compared with the threshold
value Δr_{th}. In this way, the rise of the received
signal can be detected, so that even a sharp rise of
the received signal level can be followed by the AGC

15 operation.

In the embodiment described above, at the
rise time of the received signal, the RSSI signal is
calculated with a time constant of about several
symbols to calculate the short interval average value,

20 and after the short interval average is settled, the
control signal g is preset by the short interval
average value. According to this invention, however,
the terminal b of the switch 119 may be connected
directly to the A/D converter 104 without using the

25 short interval average calculation circuit 116. In
this case, the switching control unit 118 turns the
switch 119 from terminal a to terminal b when the
difference value Δr reaches the threshold value Δr_{th}

(i.e. when the rise is detected), and presets the
control signal g with the instantaneous value r of the
RSSI signal, immediately followed by switching from
terminal a to terminal c. Also, upon lapse of the time

5 t_1+t_2 after presetting the control signal g, the connec-
tion of the terminal d of the switch 119 is turned from
terminal c to terminal a, and the AGC operation is
performed in accordance with the long interval average
value r_L of the RSSI signal.

10   Also, in the determining operation (2) of the
embodiment described above, the switch 119 has the
terminal c to which no signal is applied, and by
connecting the terminals c and d, the application of
the input signal is prevented. As an alternative, any

15 means can of course be employed obviously in which the
switch 119 is disconnected by the signal from the
switching control unit 118. As still another alterna-
tive, in the determining operation (2), the immediately
preceding gain set for the amplifier 102 may be main-

20 tained by preventing, by disconnection, for example,
the control signal g from being applied to the
amplifier 102 from the gain control unit 110.

       Also, in the embodiment of Fig. 9, the long
interval average calculation circuit 115, the short

25 interval average calculation circuit 116, the adder
117, the switching control unit 118, the switch 119 and
the gain control unit 110 may be processed by a
microcomputer such as a DSP (digital signal processor).

Fig. 13 is a block diagram showing such a configuration

of the AGC circuit according to another embodiment of

the invention. The functions of the component elements

115 to 119 in Fig. 9 are implemented, for example, by a

5 DSP 200. The processing operation of the DSP 200 will

be explained with reference to the flowchart of Fig.

14.

First, in step 140, the long interval average

value r_{Li} and the short interval average value r_{si} corre-

10 sponding to the latest instantaneous value ri input

from the A/D converter 104 are determined. Then, the

difference value Δri (= ri - r_{Li}) between the instan-

taneous value ri and the long interval average value r_{Li}

is calculated (step 142) thereby to determine whether

15 the difference value Δri has exceeded a predetermined

threshold value Δr_{th} or not (step 144). In the case

where the difference value Δri has exceeded a predeter-

mined threshold value Δr_{th}, the process proceeds to step

150, and otherwise the process is passed to step 146.

20 In step 146, the value of the control signal g is set

to a value based on the latest long interval average

r_{Li}, so that the value i is updated by 1 in step 148,

followed by returning to step 140. In step 150, the

value of the control signal g is maintained at a value

25 based on the latest long interval average r_{Li} until the

lapse of a predetermined time t_1 after the difference

value Δri has exceeded the threshold value Δr_{th}. Then,

in step 152, upon the lapse of the predetermined time

t_1, the value of the control signal g is preset and held

to a value based on the latest short interval average

value r_{si} upon the lapse of the predetermined time t_1.

Then, in step 154, upon the lapse of the predetermined

5   time t_1 and the further lapse of the predetermined time

t_2, the control signal g is set to a value based on the

latest long interval r_{Li}. After that, the process is

returned to step 140.

In the embodiment of Fig. 9, only the switch-

10   ing control unit 118 may be processed by a micro-

computer such as a DSP.

It will thus be understood from the foregoing

description that according to this invention, the AGC

operation is rapidly pulled in at the time of rise of

15   the received signal level by detecting the received

signal level. Also, as long as the received signal is

continuously received, the AGC operation is performed

at low speed with the long interval average of the RSSI

signal in order to prevent the suppression of the

20   amplitude component of the modulated wave. As a

result, a proper AGC method can be selected in accord-

ance with the receiving conditions.